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## FINAL TECHNICAL REPORT

### North Pacific Acoustic Laboratory: Deep Water Acoustic Propagation in the Philippine Sea

ONR Grant N00014-12-1-0226

Period of Performance: 01 January 2012 – 31 January 2016

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#### 1. Publications (Refereed)

Twenty (20) refereed publications were published during the period 01 January 2012 – 31 January 2016 with at least partial support from ONR Grant N00014-12-1-0226, “North Pacific Acoustic Laboratory: Deep Water Acoustic Propagation in the Philippine Sea.” Many of the publications were based on data from the 2009–2011 NPAL Philippine Sea experiments funded by ONR Grant N00014-08-1-0840, although some additional work on deep-water ocean acoustics is also listed.

Fourteen (14) of these publications appeared in the “Special Issue on Deep-water Ocean Acoustics” in the *Journal of the Acoustical Society of America* (Vol. 134, No. 4, Pt. 2 of 2, October 2013).

Chandrayadula, T. K., Colosi, J. A., Worcester, P. F., Dzieciuch, M. A., Mercer, J. A., Andrew, R. K., and Howe, B. M. (2013). “Observations and transport theory analysis of low frequency, acoustic mode propagation in the Eastern North Pacific Ocean,” *J. Acoust. Soc. Am.* **134**, 3144–3160.

Chandrayadula, T. K., Wage, K. E., Worcester, P. F., Dzieciuch, M. A., Mercer, J. A., Andrew, R. K., and Howe, B. M. (2013). “Reduced rank models for travel time estimation of low order mode pulses,” *J. Acoust. Soc. Am.* **134**, 3332–3346.

Colosi, J. A., Van Uffelen, L. J., Cornuelle, B. D., Dzieciuch, M. A., Worcester, P. F., Dushaw, B. D., and Ramp, S. R. (2013). “Observations of sound-speed fluctuations in the western Philippine Sea in the spring of 2009,” *J. Acoust. Soc. Am.* **134**, 3185–3200.

Colosi, J. A., and Worcester, P. F. (2013). “Introduction to special issue on deep water ocean acoustics,” *J. Acoust. Soc. Am.* **134**, 3115.



Dzieciuch, M. A., Cornuelle, B. D., and Skarsoulis, E. K. (2013). "Structure and stability of wave-theoretic kernels in the ocean," J. Acoust. Soc. Am. **134**, 3318–3331.

Farrell, W. E., and Munk, W. (2013). "Surface gravity waves and their acoustic signatures, 1–30 Hz, on the mid-Pacific sea floor," J. Acoust. Soc. Am. **134**, 3134–3143.

Freeman, S. E., D'Spain, G. L., Lynch, S. D., Stephen, R. A., Heaney, K. D., Murray, J. J., Baggeroer, A. B., Worcester, P. F., Dzieciuch, M. A., and Mercer, J. A. (2013). "Estimating the horizontal and vertical direction-of-arrival of water-borne seismic signals in the northern Philippine Sea," J. Acoust. Soc. Am. **134**, 3282–3298.

Powell, B. S., Kerry, C. G., and Cornuelle, B. D. (2013). "Using a numerical model to understand the connection between the ocean and acoustic travel-time measurements," J. Acoust. Soc. Am. **134**, 3211–3222.

Skarsoulis, E. K., Cornuelle, B. D., and Dzieciuch, M. A. (2013). "Long-range asymptotic behavior of vertical travel-time sensitivity kernels," J. Acoust. Soc. Am. **134**, 3201–3210.

Stephen, R. A., Bolmer, S. T., Udovydchenkov, I. A., Worcester, P. F., Dzieciuch, M. A., Andrew, R. K., Mercer, J. A., Colosi, J. A., and Howe, B. M. (2013). "Deep seafloor arrivals in long range ocean acoustic propagation," J. Acoust. Soc. Am. **134**, 3307–3317.

Udovydchenkov, I. A., Brown, M. G., Duda, T. F., Worcester, P. F., Dzieciuch, M. A., Mercer, J. A., Andrew, R. K., Howe, B. M., and Colosi, J. A. (2013). "Weakly dispersive modal pulse propagation in the North Pacific Ocean," J. Acoust. Soc. Am. **134**, 3386–3394.

Van Uffelen, L. J., Nosal, E.-M., Howe, B. M., Carter, G. S., Worcester, P. F., Dzieciuch, M. A., Heaney, K. D., Campbell, R. L., and Cross, P. S. (2013). "Estimating uncertainty in subsurface glider position using transmissions from fixed acoustic tomography sources," J. Acoust. Soc. Am. **134**, 3260–3271.

White, A. W., Andrew, R. K., Mercer, J. A., Worcester, P. F., Dzieciuch, M. A., and Colosi, J. A. (2013). "Wavefront intensity statistics for 284-Hz broadband transmissions to 107-km range in the Philippine Sea: Observations and modeling," J. Acoust. Soc. Am. **134**, 3347–3358.

Worcester, P. F., Dzieciuch, M. A., Mercer, J. A., Andrew, R. K., Dushaw, B. D., Baggeroer, A. B., Heaney, K. D., D'Spain, G. L., Colosi, J. A., Stephen, R. A., Kemp, J. N., Howe, B. M., Van Uffelen, L. J., and Wage, K. E. (2013). "The North Pacific Acoustic Laboratory deep-water acoustic propagation experiments in the Philippine Sea," J. Acoust. Soc. Am. **134**, 3359–3375.

Another six refereed papers that appeared during this period were also at least partially supported by ONR Grant N00014-12-1-0226 (in chronological order):

## 2012

Udovydchenkov, I. A., Brown, M. G., Duda, T. F., Mercer, J. A., Andrew, R. K., Worcester, P. F., Dzieciuch, M. A., Howe, B. M., and Colosi, J. A. (2012). "Modal analysis of the range evolution of broadband wavefields in the North Pacific Ocean: Low mode numbers," *J. Acoust. Soc. Am.* **131**, 4409–4427.

Udovydchenkov, I. A., Stephen, R. A., Duda, T. F., Bolmer, S. T., Worcester, P. F., Dzieciuch, M. A., Mercer, J. A., Andrew, R. K., and Howe, B. M. (2012). "Bottom interacting sound at 50 km range in a deep ocean environment," *J. Acoust. Soc. Am.* **132**, 2224–2231.

## 2013

Dushaw, B. D., Worcester, P. F., Dzieciuch, M. A., and Menemenlis, D. (2013). "On the time-mean state of ocean models and the properties of long range acoustic propagation," *J. Geophys. Res. Oceans* **118**, 4346–4362.

## 2014

Dzieciuch, M. A. (2014). "Signal processing and tracking of arrivals in ocean acoustic tomography," *J. Acoust. Soc. Am.* **136**, 2512–2522.

## 2015

Andrew, R. K., White, A. W., Mercer, J. A., Dzieciuch, M. A., Worcester, P. F., and Colosi, J. A. (2015). "A test of deep water Rytov theory at 284 Hz and 107 km in the Philippine Sea," *J. Acoust. Soc. Am.* **138**, 2015–2023.

Mikhalevsky, P. N., Sagen, H., Worcester, P. F., Baggeroer, A. B., Orcutt, J., Moore, S. E., Lee, C. M., Vigness-Raposa, K. J., Freitag, L., Arrott, M., Atakan, K., Beszczynska-Möller, A., Duda, T. F., Dushaw, B. D., Gascard, J. C., Gavrilov, A. N., Keers, H., Morozov, A. K., Munk, W. H., Rixen, M., Sandven, S., Skarsoulis, E., Stafford, K. M., Vernon, F., and Yuen, M. Y. (2015). "Multipurpose acoustic networks in the Integrated Arctic Ocean Observing System," *Arctic* **68**, 11–27.

## 2. Publications (Unrefereed)

The following unrefereed publications, including conference papers and reports, were at least partially supported by ONR Grant N00014-12-1-0226 (in chronological order):

## 2012

Southall, B., Dushaw, B. D., Moore, S. E., Howe, B. M., Clark, C., Gedamke, J., and Worcester, P. F. (2012). "Ocean acoustic monitoring in IOOS: Tools for measuring natural systems and human impacts," Community White Paper, *IOOS (Integrated Ocean Observing System) Summit 2012* (Herndon, Virginia).



Stephen, R. A., Bolmer, S. T., Udovydchenkov, I. A., Dzieciuch, M. A., Worcester, P. F., Andrew, R. K., Mercer, J. A., Colosi, J. A., and Howe, B. M. (2012). "Analysis of Deep Seafloor Arrivals Observed on NPAL04," *WHOI Technical Report WHOI-2012-09* (Woods Hole Oceanographic Institution, Woods Hole, Massachusetts), 88 pp.

Wage, K. E., Buck, J. R., Dzieciuch, M. A., and Worcester, P. F. (2012). "Experimental validation of a random matrix theory model for dominant mode rejection beamformer notch depth," in *IEEE Statistical Signal Processing Workshop (SSP) 2012* (IEEE, Ann Arbor, Michigan), pp. 816–819.

## 2013

Baxa, B. M., D'Spain, G. L., Worcester, P. F., Dzieciuch, M. A., Heaney, K. D., Mercer, J. A., and Baggeroer, A. B. (2013). "Comparison of statistics of controlled source tones and single ship noise in the deep ocean," *Proc. Mtgs. Acoust.: 21st International Congress on Acoustics/165th Meeting of the Acoustical Society of America/52nd Meeting of the Canadian Acoustical Association* (Montreal, Canada), 070027.

Colosi, J. A., Chandrayadula, T. K., Fischer, J., Coby, W., Dushaw, B. D., Dzieciuch, M. A., and Worcester, P. F. (2013). "The effects of internal tides on phase and amplitude statistics in the Philippine Sea," *Proc. Mtgs. Acoust.: 21st International Congress on Acoustics/165th Meeting of the Acoustical Society of America/52nd Meeting of the Canadian Acoustical Association* (Montreal, Canada), 070023.

McPeak, S. P., D'Spain, G. L., Stephen, R. A., von der Heydt, K., and Worcester, P. F. (2013). "OBSANP Data Acquisition Sytem: Operator's Manual and System Overview," *WHOI Technical Report WHOI-2013-06* (Woods Hole Oceanographic Institution, Woods Hole, Massachusetts), 54 pp.

Sandven, S., Sagen, H., Bertino, L., Beszczynska-Möller, A., Fahrbach, E., Worcester, P. F., Dzieciuch, M. A., Walczowski, W., Wieczorek, P., Skarsoulis, E., Morozov, A. K., Dumont, D., Dushaw, B. D., Lee, C. M., and Hansen, E. (2013). "The Fram Strait integrated ocean observing and modelling system," in *Sustainable Operational Oceanography: Proceedings of the Sixth International Conference on EuroGOOS* (EuroGOOS Office, Sopot, Poland), pp. 50–58.

Van Uffelen, L. J., Howe, B. M., Nosal, E.-M., Carter, G. S., Worcester, P. F., and Dzieciuch, M. A. (2013). "Long-range glider localization using broadband acoustic signals and a linearized model of glider motion," in *Oceans 2013* (IEEE, San Diego, California).

Van Uffelen, L. J., Nosal, E.-M., Howe, B. M., Carter, G., Worcester, P. F., Dzieciuch, M. A., Heaney, K. D., Campbell, R. L., and Cross, P. (2013). "Towards subsurface positioning of gliders using fixed acoustic tomography sources," Proc. Mtgs. Acoust.: 21st International Congress on Acoustics/165th Meeting of the Acoustical Society of America/52nd Meeting of the Canadian Acoustical Association (Montreal, Canada), 005020.

Wage, K. E., Farrokhrooz, M., Dzieciuch, M. A., and Worcester, P. (2013). "Analysis of the vertical structure of deep ocean noise using measurements from the SPICEX and PhilSea experiments," Proc. Mtgs. Acoust.: 21st International Congress on Acoustics/165th Meeting of the Acoustical Society of America/52nd Meeting of the Canadian Acoustical Association (Montreal, Canada), 070041.

## **2014**

Stephen, R. A., Worcester, P. F., Udovydchenkov, I. A., Aaron, E., Bolmer, S. T., Carey, S. D., McPeak, S. P., Swift, S. A., and Dzieciuch, M. A. (2014). "Ocean Bottom Seismometer Augmentation in the North Pacific (OBSANP) – Cruise Report," *WHOI Technical Report WHOI-2014-03* (Woods Hole Oceanographic Institution, Woods Hole, Massachusetts), 241 pp.